MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1 2022/2023 (TERM ID 2210)

EEL1206 – INTRODUCTION TO MACHINES AND POWER SYSTEMS

(EE, CE, MCE, ME, TE, OPE, NT)

15 FEBRUARY 2023
9.00 a.m - 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of **9** pages including the cover page and Appendix. There are **FOUR** questions in this paper.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of marks for each question is given.

3. Some useful formulae are given in the Appendix section.

4. Please write all your answers in the Answer Booklet provided.

Question 1

(a) Figure Q1(a) depicts a ferromagnetic core structure with a relative permeability of 2200. The depth of the core is 8 cm, and the other dimensions of the core are indicated in the diagram. A current $i = 3.75$ A flows through a 950-turn coil wrapped around the left leg of the core. Due to the fringing effect, the effective area of the air gap is 12% larger than the physical core area.
(Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H/m)

(i) Determine the total reluctance of the core structure. [5 marks]

(ii) Calculate the flux density at the bottom of the core. [4 marks]

(iii) Find the magnetic field intensity of the air gap. [3 marks]

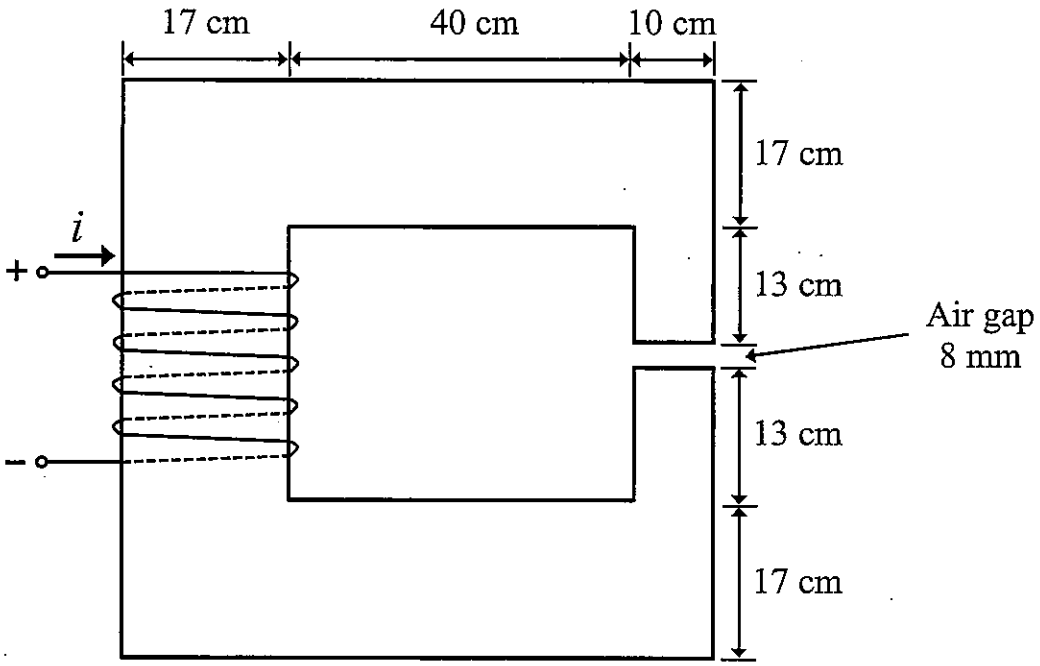

Figure Q1(a)

Continued...

(b) A balanced three-phase power system consists of an ideal Y-connected generator with a phase voltage $\mathbf{V}_{an} = 480\angle 15°$ V. A positive phase sequence is assumed for the source voltages. The generator is connected through a three-phase transmission line to a Y-connected load. The transmission line has an impedance of $(1.5 + j2.4)\ \Omega$ per phase, and the load has an impedance of $(28 + j35)\ \Omega$ per phase.

(i) Sketch the per-phase equivalent circuit of the system. [2.5 marks]

(ii) Determine the line currents $\mathbf{I}_a$, $\mathbf{I}_b$, and $\mathbf{I}_c$. [4 marks]

(iii) Calculate the total real, reactive, and apparent powers consumed by the Y-connected load. [4.5 marks]

(iv) Find the power factor of the generator. [2 marks]

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Question 2

(a) With reference to Figure Q2, explain the principle of operations of an ideal transformer.

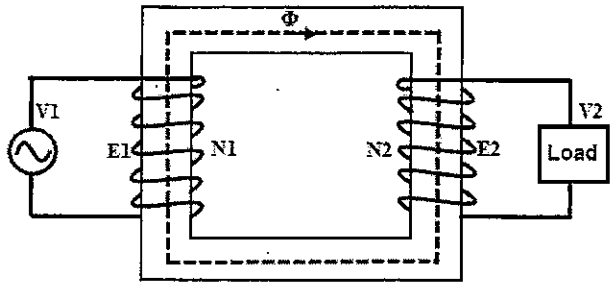

Figure Q2

[4 marks]

(b) A 200-kVA, 11000/415-V, 50-Hz single-phase power transformer has impedances as shown in Table 1. The core loss resistance and magnetizing reactance referred to the primary side are 52 kΩ and 31 kΩ, respectively.

Table 1

Primary winding	Secondary winding
$R_p = 4\ \Omega$	$R_s = 0.02\ \Omega$
$X_p = 8\ \Omega$	$X_s = 0.03\ \Omega$

(i) Determine the values for the parameters in the **approximate equivalent circuit** of this transformer referred to the secondary side.

[6 marks]

(ii) Draw the schematic diagram of the transformer's approximate equivalent circuit and label all voltages, currents and impedances.

[3 marks]

(iii) Calculate the full-load voltage regulation at 0.74 power factor (PF) lagging.

[6 marks]

(c) A 20-kVA, 2400/240-V, 60-Hz single-phase power transformer is connected to form a three-phase transformer handling 60 kVA. Suggest the connection that will produce the highest and lowest turns ratio for the three-phase transformer, respectively. Show your calculation for each case.

[6 marks]

Continued...

Question 3

(a) Briefly describe the rotor and stator construction of a synchronous generator.

[4 marks]

(b) A 200-kVA, 480-V, 50-Hz, Y-connected synchronous generator with a rated field current of 5A was tested, and the following data were taken:

$V_{T,OC} = 540\ V$

$I_{L,SC} = 300\ A$

$V_{DC} = 10V$

$I_{DC} = 25\ A$

Find the values of the armature resistance and the approximate synchronous reactance in ohms that would be used in the generator model at the rated conditions.

[6 marks]

(c) 480-V, 50-Hz, Y-connected, six-pole synchronous generator has a per-phase synchronous reactance of 1.5 Ω. Its full-load armature current is 55 A at 0.8 PF lagging. This generator has friction and windage losses of 1.5 kW and core losses of 1.5 kW at 60 Hz at full load. Since the armature resistance is being ignored, assume that the copper losses are negligible. The field current has been adjusted so that the terminal voltage is 480 V at no load.

(i) Find the speed of rotation of the generator.

[2 marks]

(ii) Determine the terminal voltage of the generator at rated load.

[4 marks]

(iii) Evaluate the efficiency and voltage regulation of the generator when it is operating at the rated current and 0.8 PF lagging?

[5 marks]

(d) At a location in the USA, it is necessary to supply 1000kW of 50Hz power. The only power sources available operate at 60Hz. Design a motor-generator set consisting of a synchronous motor driving a synchronous generator to convert the available 60Hz power to the required 50-Hz power.

[4 marks]

Continued...

Question 4

(a) Figure Q4(a) shows the one-line diagram of an electrical power system. The ratings of the various components in the power system are given as follows:

Generator, G1:	200 MVA, 54 kV, $R = 5$ %, $X = 95$ %
Generator, G2:	400 MVA, 54 kV, $R = 10$ %, $X = 95$ %
Transformer, T1:	150 MVA, 54/300 kV, $R = 2$ %, $X = 10$ %
Transformer, T2:	100 MVA, 380/28 kV, $R = 2$ %, $X = 10$ %
Motor, M:	80 MVA, 20 kV, $R = 15$ %, $X = 85$ %

The transmission line has an impedance of $(12 + j40)\ \Omega$, and the static load impedance is $(4.75 + j5.3)\ \Omega$. Consider a base apparent power of 200 MVA and a base voltage of 54 kV at the generator side.

(i) Determine the base voltages and impedances in Regions 1, 2 and 3. [5 marks]

(ii) Draw the impedance diagram of this power system, and clearly indicating all the impedances and their values in per-unit (p.u.) quantities. [8 marks]

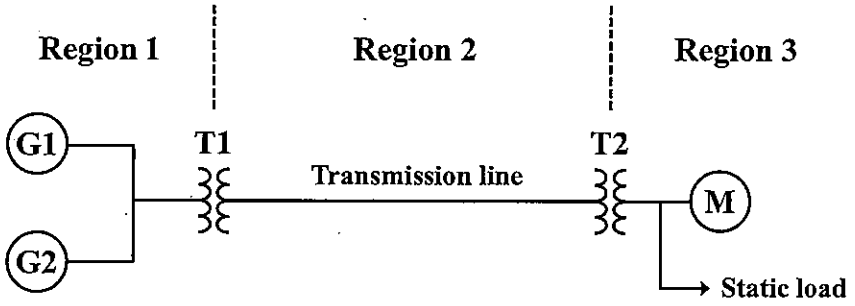

Figure Q4(a)

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(b) In Figure Q4(b), protective devices (P1, P2, ... P9) are deployed at each subfeeder within a distribution system, in order to protect customers (A, B, C, D, E) within a community from overload current conditions.

(i) Name **THREE** basic requirements of protective devices. [3 marks]

(ii) For the fault locations indicated in Figure Q4(b), identify the customer(s) who will be affected by the overcurrent fault. Justify your answer for each case.

- Fault 1
- Fault 2 [4 marks]

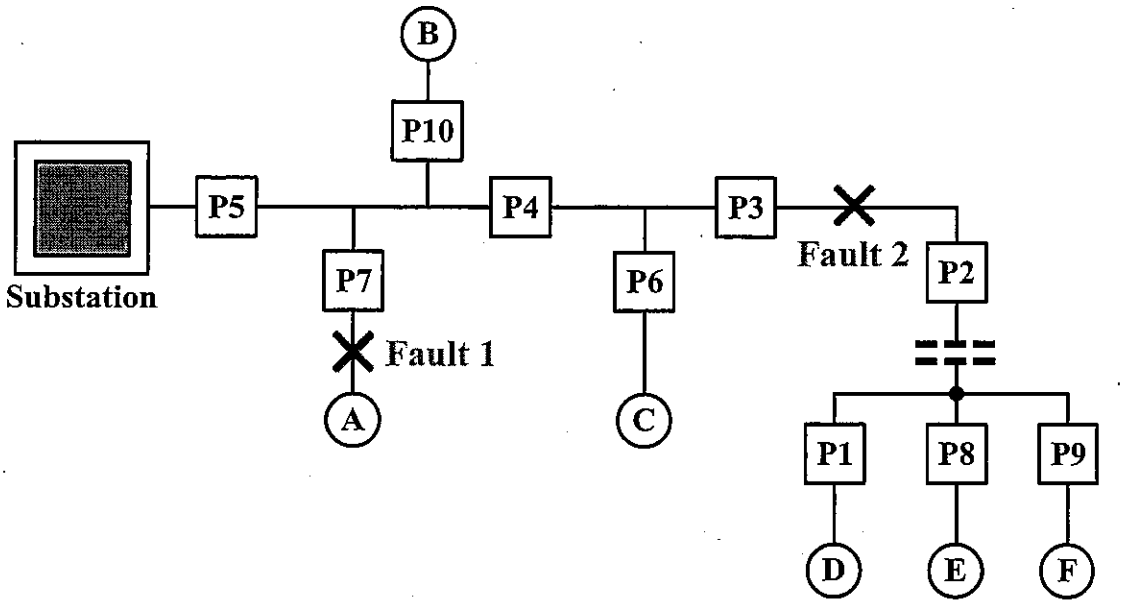

Figure Q4(b)

(c) Figure Q4(c) depicts the time-delay characteristic of an Inverse Definite Minimum Time (IDMT) overcurrent relay, which is used to protect a distribution feeder in a power system. The relay is connected to a 900:5 current transformer and a circuit breaker, and is set to operate when the load current on the feeder exceeds 1440 A.

For a chosen time-dial setting of 7, determine the operating time of the relay for a fault current of 4464 A. [5 marks]

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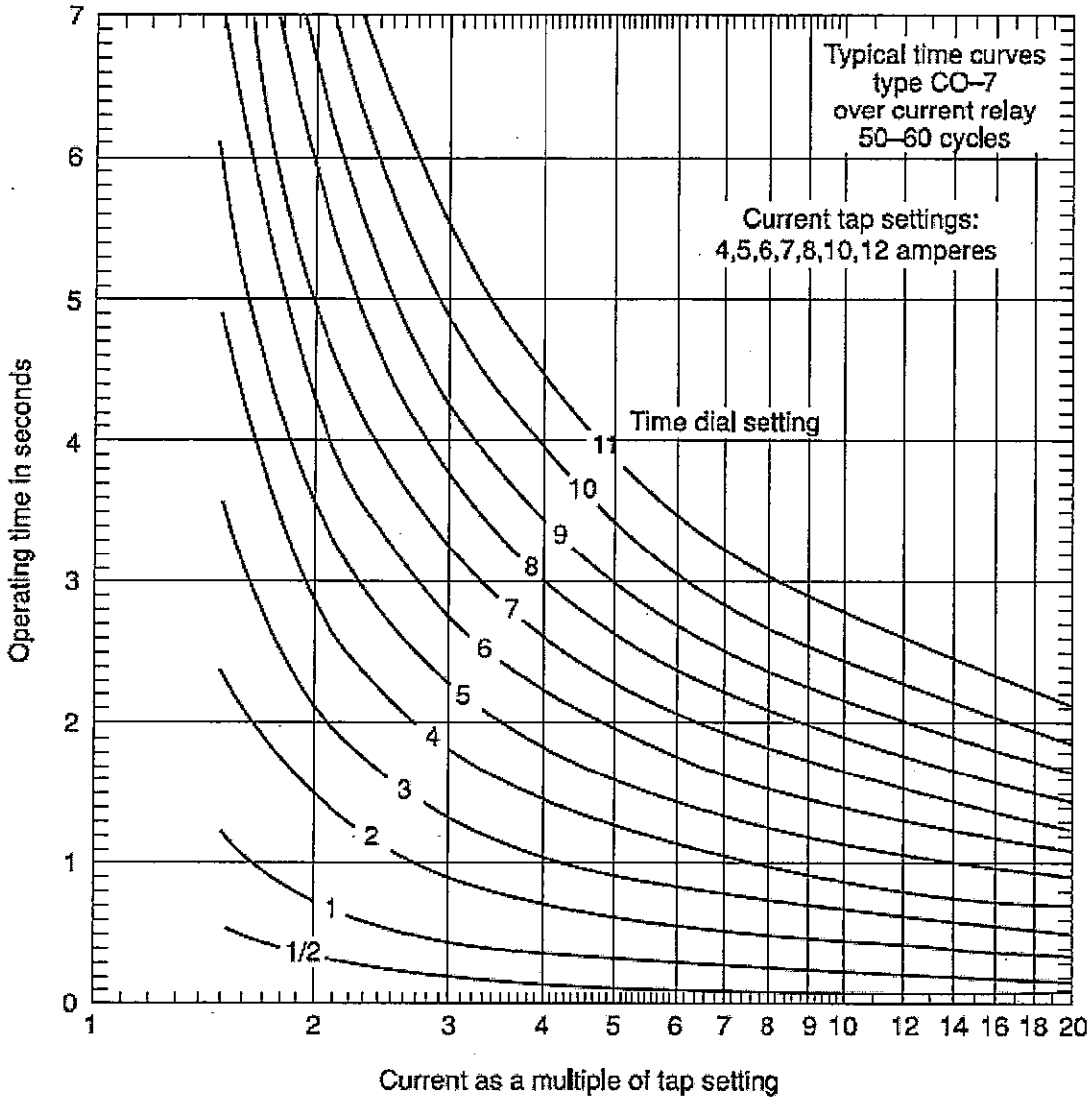

Figure Q4(c)

End of Questions

APPENDIX

Magnetic Circuits

$$H = \frac{Ni}{l_c}$$

$$B = \mu H = \mu_0 \mu_r H$$

$$\phi = BA$$

$$\Re = \frac{l_c}{\mu A}$$

$$\mathcal{F} = Ni = \phi\Re = Hl_c$$

$$\mathcal{F} = ilB \sin\theta$$

$$e_{ind} = vlB \sin\theta_1 \cos\theta_2$$

$$P = \tau\omega$$

Three-Phase Circuits

Y-Connection: $I_L = I_\phi,\ V_L = \sqrt{3}V_\phi \angle 30°$

Δ-Connection: $V_L = V_\phi,\ I_L = \sqrt{3}I_\phi \angle -30°$

Δ-Y Transformations:

$$R_a = \frac{R_{ac}R_{ab}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_b = \frac{R_{ab}R_{bc}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_c = \frac{R_{bc}R_{ac}}{R_{ac} + R_{ab} + R_{bc}}$$

Y-Δ Transformations:

$$R_{ac} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_b}$$

$$R_{ab} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_c}$$

$$R_{bc} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_a}$$

$$P_T = 3|V_\phi||I_\phi| \cos\theta = \sqrt{3}|V_L||I_L| \cos\theta$$

$$Q_T = 3|V_\phi||I_\phi| \sin\theta = \sqrt{3}|V_L||I_L| \sin\theta$$

$$S_T = 3|V_\phi||I_\phi| = \sqrt{3}|V_L||I_L|$$

Transformers

Turn ratio: $a = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$

Equivalent circuit (referred to primary):

$$V_s' = aV_S, \quad I_s' = \frac{I_S}{a}$$

$$R_s' = a^2R_S, \quad X_s' = a^2X_S, \quad Z_L' = a^2Z_L$$

$$R_{eqP} = R_P + a^2R_S, \quad X_{eqP} = X_P + a^2X_S$$

Equivalent circuit (referred to secondary):

$$V_P' = \frac{V_P}{a}, \quad I_P' = aI_P$$

$$R_P' = \frac{R_P}{a^2}, \quad X_P' = \frac{X_P}{a^2}$$

$$R_{eqS} = R_S + \frac{R_P}{a^2}, \quad X_{eqS} = X_S + \frac{X_P}{a^2}$$

Short-Circuit Test

$$Z_{eq} = \frac{V_{SC}}{I_{SC}}, \quad R_{eq} = \frac{P_{SC}}{{I_{SC}}^2}$$

$$X_{eq} = \sqrt{{Z_{eq}}^2 - {R_{eq}}^2}$$

Open-Circuit Test

$$R_C = \frac{{V_{OC}}^2}{P_{OC}}, \quad S_{OC} = V_{OC}I_{OC}$$

$$Q_m = \sqrt{{S_{OC}}^2 - {P_{OC}}^2}$$

$$X_m = \frac{{V_{OC}}^2}{Q_m}$$

Voltage Regulation

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

Efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

End of Paper